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THE RESPONSIBLE ROLE OF THE ATMOSPHERIC SCIENCES IN DETERMINING THE FUTURE QUALITY OF MAN'S ENVIRONMENT

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Santa Monica, California

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Rather than merely attempting to predict the probable directions of the atmospheric sciences as a discipline into the future, I would like to approach this subject from the standpoint of the question of what does atmospheric science have to contribute to the future of man? That is to say, what relevant role is to be played by our scientific discipline within the context of the progress of civilization? I approach this from the standpoint of "relevance" because we practitioners of science tend to ignore this word as being fatuous in the sense that scientific advancement and the acquisition of knowledge are its own justification. However, the legislator, the student, the layman, the man who pays the bills, are no longer satisfied by such verbiage. They are ever increasingly raising the question of relevance, and we must respond. I might add that in responding to a demand for proof of relevance it is no longer sufficient to simply enumerate the growing complex problems of society and to point out that our particular branch of science is concerned with subjects which in one way or another bear on these problems and thus dismiss the questioner. It is increasingly evident that we must become "involved" in these problems in the sense that if we truly believe that the answers to these problems bear importantly on the survival of man, then we must directly engage in their solution.

This sense of change in society's attitude towards science and scientific investigation can be found in many recent writings. One of particular interest is a recent paper by Professor Robert Morrison of

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Cornell on "Science and Social Attitudes" which was presented at a AAAS Conference on Science and the Future. Professor Morrison said

> ...it puts no great strain on one's clinical intuition to observe that large numbers of people in various parts of the world--including, perhaps most significantly, the advanced parts--are less happy about science and technology than they once were. The evidence is of various kinds. Perhaps the most quantitative is provided in the United States by the relative decline in students entering the sciences and the scientifically based professions. In some instances, such as engineering, the numbers have fallen absolutely in the face of a steady increase in the total number of potential students in each age class. Even more quantitative, and certainly more compelling to the individual scientist, is the evidence provided by the slowdown in appropriations for science. Third, one may cite the intuitions and reflections of thoughtful social clinicians like Rene Dubos, who has so courageously summarized the shortcomings of scientific approaches to human problems. True enough, he finally draws the conclusion that what we need is not less sciences but more. Nevertheless, the argument depends on a careful demonstration that science raises new problems of increasing complexity as it continues to solve the older and simpler ones.

This growing awareness of the seemingly insoluble problems produced by our complex technical society and the frustration that accompanies them has brought about, within the general public, a visible suspicion and even revulsion from the scientist and his efforts. This feeling too is expressed in Professor Morrison's paper when he says:

> The decade of the 1960's has certainly seen a slackening in public approval of science. Is this change simply a return to the earlier, more or less normal state of ignorance and indifference, or are we witnessing an actively hostile movement?

I believe the answer to the question posed by Professor Morrison is that we are indeed seeing a very definite public reaction to these apparently overwhelming complex societal problems that face us. That this reaction is essentially hostile and suspicious borne out of frustration and concern. That it manifests itself in an attempt to limit

the headlong rush of scientific progress through the only means available, the denial of funds. An amplifier of this reaction is that along with the appearance of these complex problems has been the growth of what is now called "Big Science" and the publicly infuriating demand for even larger sums of money. It must be particularly galling to the lay public to find that most of these requests to support big science are predicated once again on the self-justification of scientific advance, particularly in the face of the obvious problems that cry for solution.

Relating this trend in public and legislative opinion back to our own discipline we find that despite the fact that a large percentage of the meteorological community is engaged in the providing of a day-to-day weather service to the public, we in the atmospheric sciences are in the main as guilty as the rest of our colleagues in our reluctance to respond to the long-term needs of society. We illustrate this in our own professional society, where despite attempts to avoid this, barriers continue to grow between the forecaster and the researcher, to the point where these two areas currently exist almost as two separate professions. We also illustrated the subtle but well understood difference between meteorologists and atmospheric scientists. We have become so enamored with our numerical techniques, our big computers, and our experimental gadgetry, that they have become almost end in themselves. As a result, we too find ourselves rapidly being caught in the same "big science," and "science for the sake of science" traps that are currently plaguing many other scientific disciplines. Interestingly enough this condition prevails, despite the fact that one of the most crucial problems facing society today is that involving man's interaction with his environment. And one of the most dominant threads running through this problem is the involvement with the atmosphere. Man must learn to live and cope with his environment. It is evident that we in the atmospheric sciences have a very large and continuing part to play in addressing this challenge.

Man's general concern with his environment has grown out of the almost explosive growth of population and technology during the first half of the twentieth century. This growth has produced an increasing

concern over man's ability to conserve and, where necessary, manage his environment. The components of this potential threat to man's very existence are such things as the possible attempts to deliberately modify the environment and the possible inadvertent modification due to the activities associated with life in this highly technical society. In general, they represent a degree of complexity that does not permit easy analysis and/or understanding, and impose a threat of irreversibility from a time standpoint that underscores the need for immediate attention. In the latter case, we have reference to such conditions as dangerously polluted air over wide areas, the destruction of adequate supplies of quality water and even the inadvertent triggering of deleterious large-scale climatic changes due to little-understood attempts to modify the weather at a lesser atmospheric scale. Given sufficient time all of these are potentially reversible but the amount of time required to reverse them could make the question academic.

Man interacts with his environment in many potentially tragic ways. For example, he engages in modifying the weather either deliberately or inadvertently through his stimulation of possible energy trigger points in the atmosphere, such as the organized release of latent heat and condensation through the widespread seeding of condensation nuclei. He pollutes the air, depositing in the atmosphere large quantities of gaseous or particulate waste products which change the chemical or physical character and quality of the atmosphere. He similarly pollutes the water, depositing gaseous or particulate waste products in bodies of water which could change the chemical and physical characteristics. He eliminates the waste heat he generates (primarily from electrical generating plants) by direct deposition in bodies of water or through cooling towers into the atmosphere. Through the deposition of solid waste materials and the general extension of civilization, man radically changes the surface characteristics of the earth that determine its role in the radiation heat balance, the generation of oxygen through photosynthesis, etc. He creates new bodies of water for newly irrigated areas which increases the water vapor input into the atmosphere over wide areas and changes the general heat balance. Through the destruction of forest land and the clearing of land and deliberate or

inadvertent defoliation he produces perturbations of the local heat balance. In addition runoff and erosion as well as ecological changes produced by man's activities create even more irreversible effects in the local environment. Finally, through his insatiable need for more and more energy to support his burgeoning technology, he creates environmental changes that range from air pollution due to the burning of fossil fuels to thermopollution from the removal of waste heat.

In addition to their individual impact it is evident that many of these areas of environmental "insult" continuously feed back one upon the other. For example, one cannot discuss weather modification without also considering the effect of air and water pollution. It is not as clear, though it is demonstrable, that one must also include a consideration of global energy production and usage. The annual energy production in the world is approaching .05 percent of the surface radiation balance. It is growing at the rate of 4 percent per year and this rate doubles every 17 years. In view of this the heat produced and the chemical byproducts released in the production of this energy cannot be ignored as a possible environmental influence probably during the next 50 years. Similarly, ecological manipulations are directly affected by pesticide usage, and are indirectly affected by air pollution, water pollution, land usage, etc.

In addition to the complex technical interactions that take place one must also consider the impact of environmental change on society. Obviously, biological effects fall into this category. The environment in which we live, however, and the actions necessary to solve actual or anticipated problems can have an important impact on our economy and social structure. Thus, they must receive attention in any analysis of environmental change. For example, the solution to a pollution problem could be a relocation of the sources, elimination of the pollutant at the source, or a combination of the two. Such a solution carries a definable cost and possibly a social effect if it requires uprooting and relocating a segment of the population.

The demands of an expanding civilization increase constantly, and man's technological ability grows to satisfy them. Eventually, man will achieve the ability to affect his environment over a greatly ex-

panded time and space scale. Ignoring the often discussed troublesome problems of increased atmospheric turbidity and CO_2 content, there are still available many other examples of deliberate activities contemplated by man that could lead to major, as yet undetermined, indirect effects on the environment. Let's examine just a few examples that are based on what appears to be the laudable attempt to extend water availability over large areas for the benefit of agriculture. Their assumed impact on the environment is predicated on an estimate by Sawyer that a thermal anomaly approximating 10 percent of the net solar energy available at the surface of the earth extending over several million square kilometers for at least one month could produce a climatic variation. The specific examples are the following:

Creation of Siberian Sea: Dams on the Ob, Yenisei, and Angara Rivers could create a lake east of the Urals that would be almost as large as the Caspian Sea. This lake could be drained southward to the Aral and Caspian Seas, irrigating an area about twice the size of the Caspian Sea. The presence of this large new Sea could significantly affect the heat exchange between the surface and the atmosphere. But of equal or greater importance is the change in surface reflectivity and evaporation rate produced by the vegetation contained in the large new irrigated areas.

Creation of African Seas: This is the largest known prospect for a man-made lake. If the Congo River, which carries some 1200 cubic kilometers of water per year were dammed at Stanley Canyon (about one mile wide) it would impound an enormous lake. The Ubangi, a tributary of the Congo, would then flow northwest, joining the Shari and flowing into Lake Chad, which would grow to over 1 million square kilometers. This lake would almost equal the combined areas of the Baltic, White, Black, and Caspian Seas. The two lakes would cover 10 percent of the African continent. They could then drain north across the Sahara creating a second and larger irrigated region similar to the Nile Valley. As in the case of the Siberian Sea, the large effect would be due to both the presence of the large new body of water and the effect of the large irrigated region.

The NAWAPA Project: The North American Water and Power Alliance

would bring 100 million acre-feet of water across the Canadian border to be evaporated by irrigation in the western states. The thermal anomaly provided by the large irrigated region would at least equal the climatic variation criterion cited above.

All of these examples have been seriously proposed, and fulfill the stated criterion for a climatic variation. What is frightening is that we do not currently have the ability to assess the validity of this criterion or the extent and nature of the possible result in climatic variations. We cannot today determine whether such variations might be beneficial or deleterious, transitory or irreversible; we do not yet have the ability to quantitatively assess the total impact of such man-made changes on the total environment. Yet the plans for such programs do not exhibit concern for these problems.

It is clear, then, that man can no longer look upon this planet as an object of exploitation. Man, his society and his technology have reached the point where they are no longer a small perturbation to the balance of nature, but are rapidly becoming the controlling influence. It is imperative therefore to consider all the ramifications of man's activities to insure that he does not in the pursuit of some of his goals inadvertently destroy some of his invaluable resources. Of course man is not omniscient; he cannot hope to manage his environment flawlessly. It is not too early however to recognize that such management will be required and for man to accept the responsibility for the continued habitability of the earth.

While threats to the environment potentially grow more dangerous, the demand for an improved environment has become very much stronger in the United States. Membership in conservation organizations has mushroomed, and park facilities have become increasingly strained to accommodate users. More concern is being voiced about the fitness of the air and water and even the urban environment as a whole for human use. In response, an increasing number of pollution laws are being passed at all levels of government. The resulting pressure to do "something" is producing an enormous challenge to the scientific and technical communities that simply cannot be ignored.

My discussion so far must be recognized at best as an elementary

statement on the complexities involved and a consideration of the demands for and the potential dangers of environmental change. Yet even this statement expresses a sense of urgency about this problem that is enhanced by the realization that many of the tools and techniques required to even begin an attack are not completely available, while man is very close to seriously affecting his gross environment. Air and water pollution are significant and growing problems, and weather-modification attempts on a significantly large atmospheric scale are being discussed. Efforts to date have concentrated on understanding the technical aspects of the problem. Mathematical models exist for various scales of atmospheric and ocean dynamics, and are just reaching a stage that will permit some degree of numerical experiment. Such experiments promise to help us better understand weather modification and air and water pollution. Similarly work is underway to examine the biological aspects of air and water pollution, ecological modification, and pesticide usage. Agricultural scientists and agronomists have examined the technical aspects of land management and usage, and considerable research continues in water storage, transport and management. Significantly, however, almost no attempts have been made to date to examine the entire problem of environmental conservation and management involving the interlocking environmental effects described and the social and economic impact. Yet this total problem is as critical as the individual problem.

After this rather lengthy introduction we may now return to give a brief answer to the question at issue, namely, the future of atmospheric sciences. It should be no surprise at this point that I feel very strongly that the future of our science is intimately intertwined with the necessity of answering the challenge posed by the previously stated problems. This does not mean that I feel that a great deal of research on the atmosphere will not continue as usual, but rather that we will ultimately see a large number of good atmospheric scientists becoming increasingly involved in addressing problems similar to those described. Further, we will see new atmospheric scientists being given the opportunity to be trained much more broadly than is now possible, allowing and encouraging them to interact with many disciplines.

The major impetus for this will be the availability of support and the forming of new research and educational entities dedicated to the solution and analysis of these problems. In effect, I believe we will see the creation of a new discipline probably called Environmental Science or Environmental Studies, of which atmospheric science will be an important component. We can already see evidence of this occurring in the fact that colleges and departments of the Environmental Sciences are coming into being. Typical of these is one recently formed by Professor Fred Sargent on the University of Wisconsin-Green Bay Campus, and dedicated to attempting to train people to work on problems of man and his environment. As presently conceived this will be done by attempting to academically educate these people in a wide range of disciplines through the mechanism of having the students select a broad theme such as air pollution rather than a discipline such as chemistry. They presently plan to do this at the undergraduate level. My personal opinion is that I would prefer to see this accomplished at the graduate level so as to permit one to be trained well in a single discipline before broadening his area of interest. This objection, however, does not detract from the fact that this is an interesting experiment in education and an indicator of possible future trends.

In another example of what is currently happening, a National Academy of Science's summer study on problems of the environment was held during the month of August at Stanford University. One major stated recommendation was for the creation of analytical and research groups on a national scale, capable of addressing the multifaceted character of the total environmental problem. In all of these discussions, the atmospheric sciences loom as one of the key components of such institutional solutions, but only in combination with other disciplines that are currently foreign to our normal concept of research colleagues. Here again, however, the emphasis was not on pointing the research towards any specific narrow discipline but rather on addressing a large complex problem.

In conclusion, then, I cannot escape the belief that a time will come when there will be a class of atmospheric scientists who are eminently trained as Environmental Scientists. In this process they will

learn to work in, with, and speak the language of disciplines such as Economics, Biology, Ecology, etc. They will learn to respond to questions raised by colleagues in these other disciplines and in turn to significantly challenge them. In short, to become part of a team that will permit them to apply their knowledge and talents directly to solving some of the most pressing problems of our civilization. To my way of thinking this represents a bright and rewarding future for the atmospheric sciences.